Perception of music and speech: Focus on rhythm processing

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MUSIC & LANGUAGE

Fundamental, basic research

- Acoustic and structural similarities
- pitch, timbre, rhythm
- syntactic structures

- Shared cognitive and neural correlates

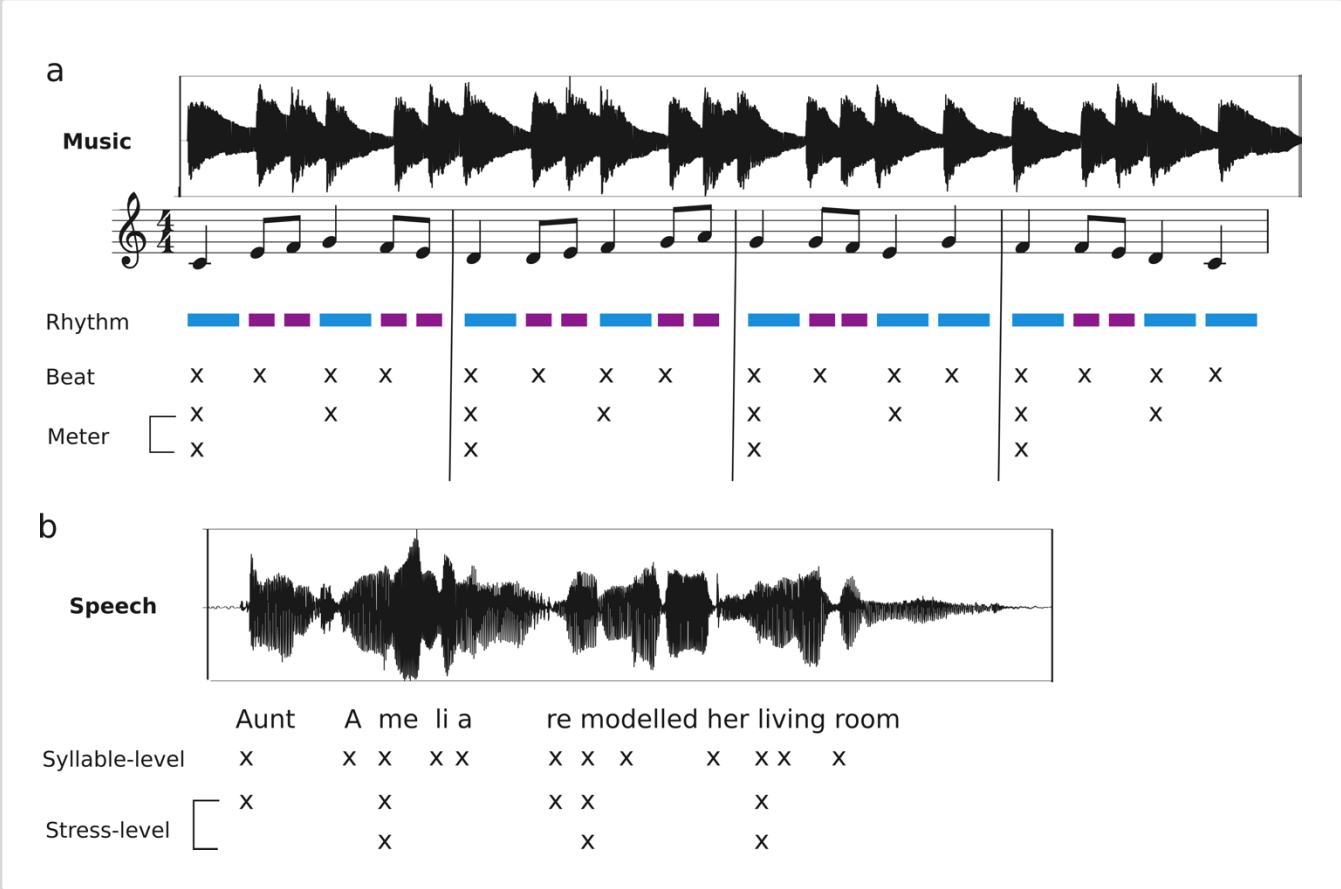
- Influence of **musical expertise** and/or musical training and/or stimulation

Perspectives for stimulation, training,
- in education and rehabilitation

Developmental Language Disorders, hearing impairement, Parkinson Disease, etc.

Rhythm in music and speech

Rhythm = temporal patterns created by the onsets and durations of acoustic events in a sequence



Similarities

- Acoustic Cues: duration (timing), frequency (pitch), amplitude/intensity (loudness), timbre (instrument/voice quality)
- Hierarchical Structure

Differences

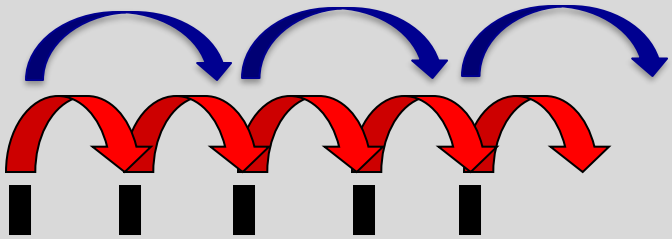
Regularity: Isochronous for music; patterns of prominence, grouping, and lexical stress for speech.

(Fiveash et al., 2022, Neuropsy)

Dynamic attending theory

(Jones & Boltz, 1989; Large & Jones, 1999)

Attention as a dynamic phenomenon, guided by temporal regularities



Synchronization of internal oscillators to external regularities (entrainment)

Orienting (auditory) attention over time

Development of expectations about temporal occurrence of next event

Facilitated processing of events in regular structures (vs. irregular structures)

Facilitated processing of events at expected time points (vs. too early/late)

Music *(e.g., Boltz, 1993; Tillmann & Lebrun, 2005)*

Language: words, syntax, semantics *(e.g., Quéné & Port, 2005; Schmidt-Kassow & Kotz, 2008)*

Learning of new structures/grammars *(e.g., Selchenkova et al., 2014; Schultz et al., 2013; Hoch et al., 2013)*

➡ **Perceptual and cognitive sequencing, structural integration**

Relevant for phonological processing, syntax and reading

Rhythm *in music and speech processing*

Competences | **Deficits** | **Training** | **Stimulation**

Rhythm perception and production
Rhythm discrimination tasks
Beat synchronization

Reading and spelling

(e.g., Holliman et al., 2010; Tierney & Kraus, 2013; *Kertész & Honbolygó, 2021)*

Phonological processing

(e.g., Degé et al., 2015; Cohrdes et al., 2016; Ozernov-Palchik et al., 2018; Carr et al., 2014; Politimou et al., 2019)

Grammar processing

- **expressive grammar** *(e.g., Gordon et al., 2015)*
- **receptive grammar** *(e.g., Lee et al., 2020; Swaminanthan & Schellenberg, 2019)*

Longitudinal approaches *(no intervention)*

Beat synchronization → **Reading** *(David et al., 2007)*
Age: 6y (grade 1) — Age: 7-9y (Grade 2 to 5)

Tapping task (SMS) → **Reading and speling** *(Kertész & Honbolygó, 2023)*
Age: 7y — Age: 9y

Typically developping children

Rhythm *in music and speech processing*

Competences | **Deficits** | **Training** | **Stimulation**

Rhythm perception and production
Rhythm discrimination tasks
Beat synchronization

Neurodevelopmental language disorders

Developmental Language Disorder DLD

→ *SLI: speech and language impairment; specific language impairment)*

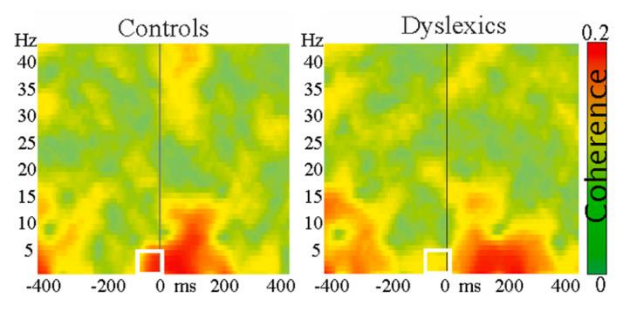
Dyslexia

e.g., tapping to a metronome
(predict rime awareness, spelling, word/nonword reading, etc.)

e.g., beat perception performance
(predict word/nonword reading, phonological awareness)

(e.g., Weinert, 1992; Sallat & Stachowiak, 2005; Corriveau & Goswami, 2009)

(e.g., Overy et al., 2003; Muneaux et al., 2004; Thomson & Goswami, 2008; Huss et al., 2011; Flaugnacco et al., 2014)



(from Soltes et al., 2013)

Atypical neural tracking of temporal regularity in verbal and tonal materials
(e.g., delta oscillations; entrainment; response to speech edges)

(e.g., Soltesz et al.; 2013; Keshavarzi et al., 2022; Di Liberto et al., 2018; Molinaro et al., 2016)

Rhythm *in music and speech processing*

Competences | **Deficits** | **Training** | **Stimulation**

Rhythm perception and production
Rhythm discrimination tasks
Beat synchronization

Neurodevelopmental language disorders

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Dyslexia

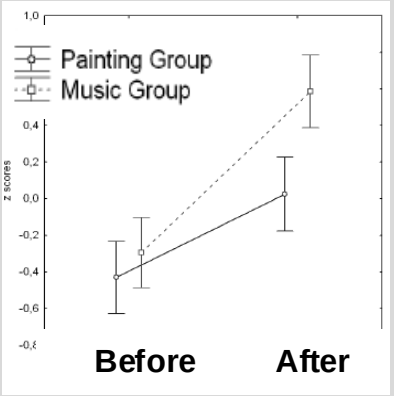
Rhythmic training programs

(e.g., Overy et al., 2003; Flaugnacco et al., 2014)

→ **benefits phonological awareness and reading**

(30 weeks)

or



(Flaugnacco et al., 2015)

Rhythm *in music and speech processing*

Competences | **Deficits** | **Training** | **Stimulation**

Can the rhythmicity of a musical prime influence subsequent syntax processing in TD children and children with DLD and dyslexia?

Rhythmic prime

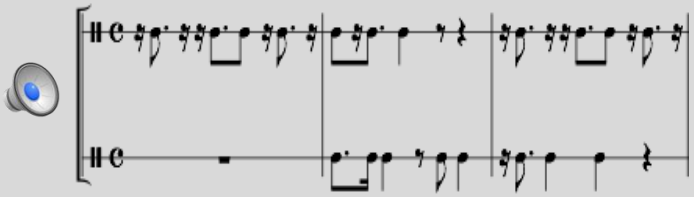
Grammaticality/ungrammaticality judgments
(auditory presentation)

50%

50%

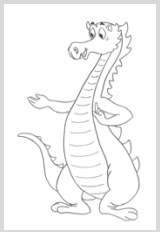
REGULAR

IRREGULAR

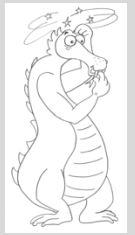


32-s musical excerpts

Grammatically correct sentences



3 types of syntax violations
(gender, number or person
e.g., Laura ont oublié son violon)



Musical Prime → 6 sentences (3 G, 3 UG)

Musical Prime → 6 sentences (3 G, 3 UG)

Etc.

Better performance after regular prime?
or only creating response bias?

Performance analyses with SDT: d′ and bias c

(Przybylski et al., 2013)

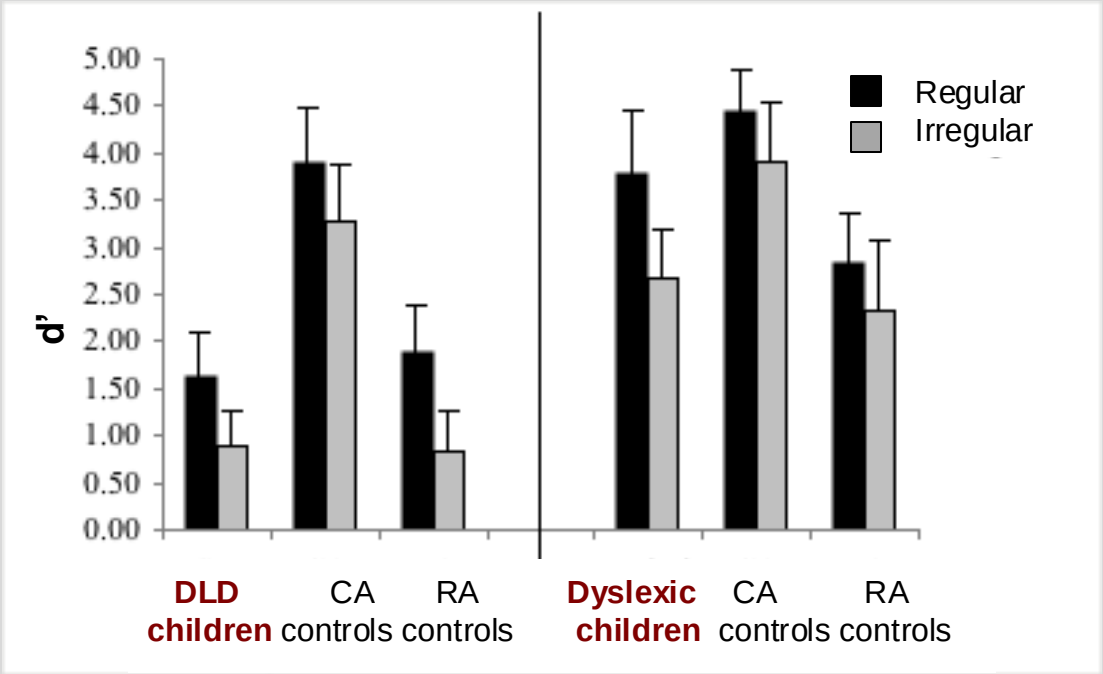
Can the rhythmicity of a musical prime influence subsequent syntax processing in children with DLD and dyslexia?

2) **Dyslexic children** diagnosed with a phonological dyslexia

DYS children: n=10
Mean chronological age: 9y;9mo
Mean reading age: 7y, 7mo

CONTROL group 1 **CA**
Matched for **chronological** age

CONTROL group 2 **RA**
Matched for **reading** age



Better performance after regular prime

The effect of musical prime was not accompanied by a difference in response bias c

Better performance after regular prime

(Przybylski et al., 2013)

Can the rhythmicity of a musical prime influence subsequent syntax processing in children with DLD and dyslexia?

YES

For DLD and dyslexic children (and matched controls):
Better performance after the regular prime than the irregular prime, despite patients' deficits in rhythm and meter processing

Replicated in English for TD children: Chern et al. 2018
Hungarian for DLD children: Ladanyi et al. (2021)
French in adults with more subtle syntax errors (Canette et al., 2021)
& Jabberwocky sentences (György et al., 2024)

Effect of prior music stimulation (not simultaneous) on speech processing
Abstract level, not matched for each sentence

In agreement with data for patients with basal ganglia lesions or Parkinson's disease *(Kotz et al., 2005, 2009)*

Regular musical prime restored P600 *(Kotz et al., 2005)*

versus no P600 without prime *(Kotz et al., 2003)*

Does the rhythmicity of a musical prime influence the P600?

13 dyslexic adults *(avg: 23.2 years old)*
13 matched control adults

Does the rhythmicity of a musical prime influence the P600?

13 dyslexic adults

with mainly phonological difficulties
(→ phonological or mixed form of dyslexia)
(e.g., increased reading times for pseudo-words or irregular words, reduced orthographic skills)

13 control adults

(matched for age, education, musical background, gender)

Testing of rhythm processing capacities

Rhythm production:
- Spontaneous regular tapping at preferred rate
- tapping along isochronous sequences at 400, 550 and 600ms
- tapping along the beat of musical excerpts

Rhythm perception:
- Judging whether the sound of a metronome was aligned or not with the beat of musical excerpts
- Confidence level in their response and response times

Correlation between syntax tasks performance and some rhythm percepton / production data

Rhythmic prime

REGULAR IRREGULAR

More various musical primes

Grammaticality judgments

	d'
Dyslexic group	*3.76 (0.52)*
Control group	*4.02 (0.43)*

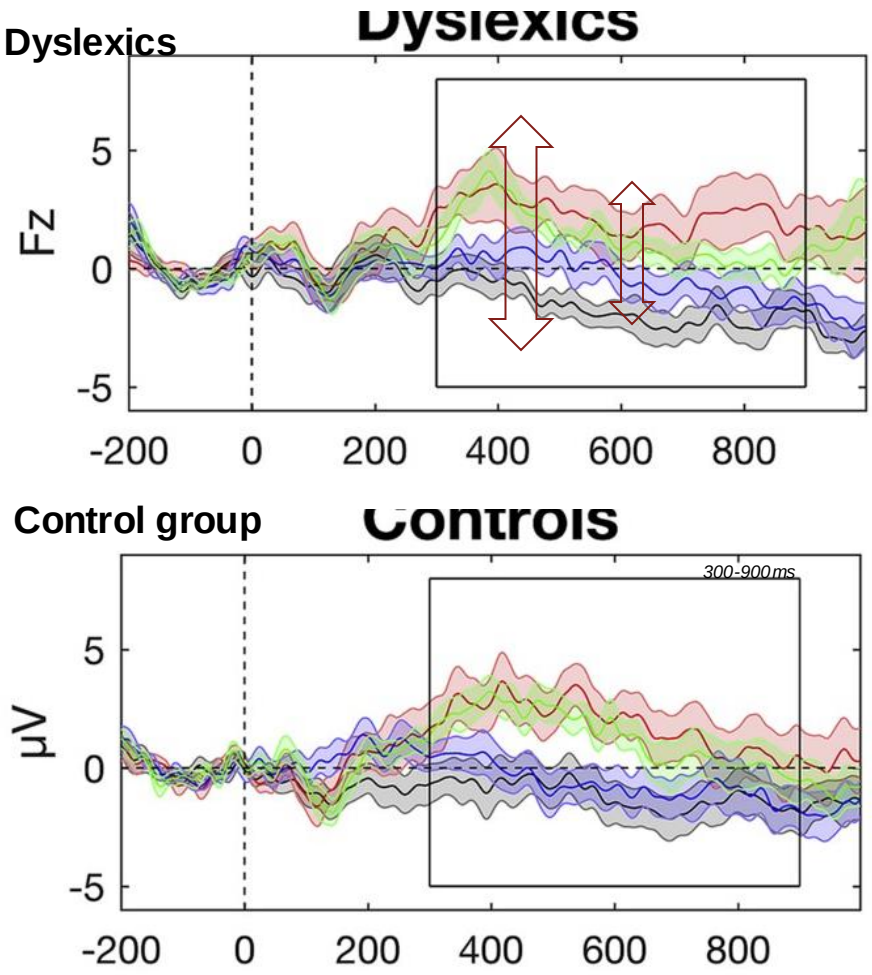
Additional test with more subtle morpho-syntactic errors:

*EXAMPLE: C'est moi qui ai/**a** fait le repas pour ce soir.*

	d'
Dyslexic group	*1.91 (0.58)*
Control group	*2.80 (0.62)*

(Canette et al., 2020a, b)

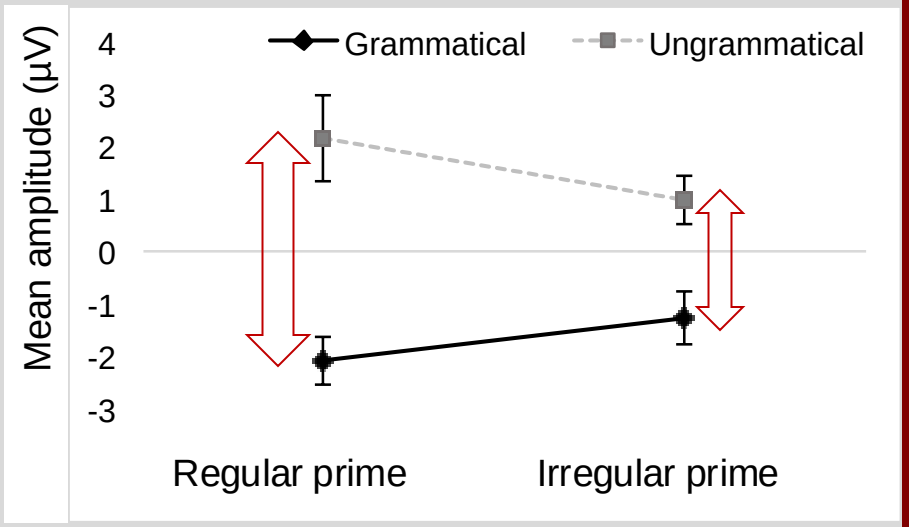
Does the rhythmicity of a musical prime influence the P600?



P600 for grammatical errors

For both dyslexics and controls

… with later peak for dyslexics at posterior sites



Interaction Prime x Grammaticality

(Canette et al., 2020a, b)

Can the rhythmicity of a musical prime influence subsequent syntax processing in children with DLD and dyslexia?

YES

For DLD and dyslexic children (and matched controls):
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in Hungarian for DLD children: Ladanyi et al. (2021)
in French in adults with more subtle syntax errors (Canette et al., 2021)

Effect of prior music stimulation (not simultaneous) on speech processing
Abstract level, not matched for each sentence

In agreement with data for patients with basal ganglia lesions or Parkinson's disease *(Kotz et al., 2005, 2009)*

→ Regular musical prime restored P600 *(Kotz et al., 2005)*

versus no P600 without prime *(Kotz et al., 2003)*

Enhanced P600 after regular prime (vs. irregular prime) in dyslexic adults and controls

- Impaired performance in some rhythm perception and production tasks
  + link with syntax processing

Can the rhythmicity of a musical prime influence subsequent syntax processing in children/adults with DLD and dyslexia?

YES

BUT Comparison between **regular and irregular** musical primes

Important question for perspectives of training and rehabilitation:

Does a regular musical prime **facilitate** subsequent syntax processing when compared to a more neutral baseline prime?

Does a regular musical prime **facilitate** subsequent **syntax processing?**

PRIME → Grammaticality judgments

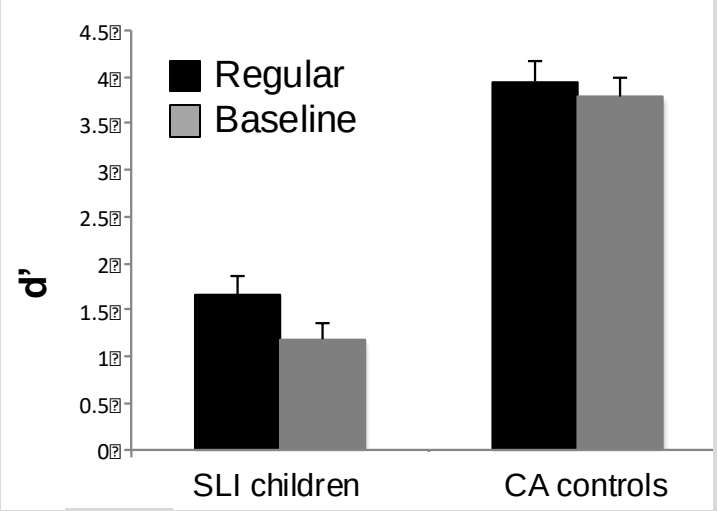
REGULAR PRIME

BASELINE (neutral) PRIME

Environmental sound scene without temporal regularity
(e.g., playground, street scene)

DLD children: n=16
Mean chronological age: 9y;7mo
Mean reading age: 6y, 11mo

CONTROL group **CA**
Matched for **chronological** age



Better performance after regular prime

The effect of musical prime was not accompanied by a difference in response bias c

(Bedoin et al., 2016)

Does a regular musical prime **facilitate** subsequent **syntax processing?**

PRIME → Grammaticality judgments

REGULAR PRIME

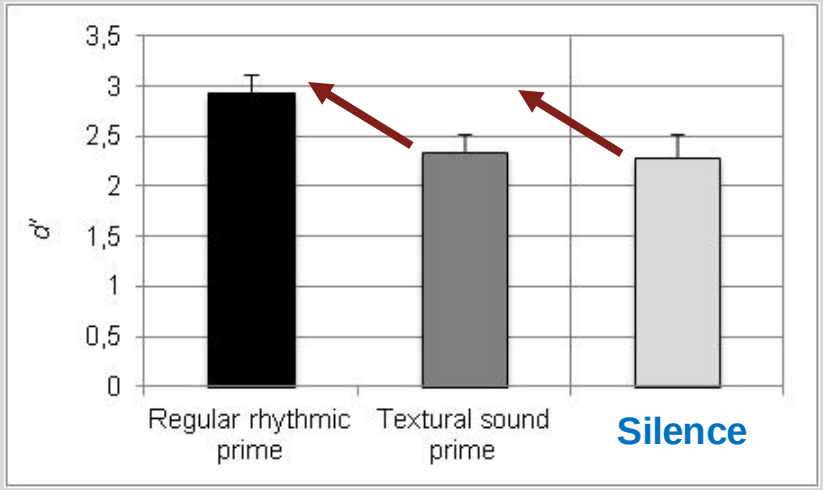
BASELINE (neutral) PRIME

Textural sound prime: *contemporary music without rhythmic regularity*

Silence

Typically developing children: n=16
Mean chronological age: 8y;0mo
SD = 6 mo [7y 2mo; 8y 11mo]

Typically developing children: n=16
Mean chronological age: 7y;3mo
SD = 5mo [6y 10mo; 8y 7mo]



Better performance after regular prime

The effect of musical prime was not accompanied by a difference in response bias c

→ **Promising findings in regard to the use of musical primes in training**

(See also Ladanyi et al., 2020) *(Canette et al., 2019)*

Can the rhythmicity of a musical prime enhance the efficiency of therapeutic training and exercises, such as for syntax processing ?

Groupe 1:	Test 1	**Training** sessions with musical **regular primes**	Test 2	**Training** sessions with neutral **baseline primes**	Test 3
Groupe 2:	Test 1	**Training** sessions with neutral **baseline primes**	Test 2	**Training** sessions with musical **regular primes**	Test 3

Training: Exercises on grammaticality judgments and syntax comprehension

8 weakly sessions (20min)

Prime → *Exercises* Prime → *Exercises* *etc.*

Tests:

- Grammaticality judgments
- Syntax comprehension
- Phonological segmentation: repetition of words/pseudowords
- Attention tasks
- Memory tasks

Regular prime vs. Baseline prime

(Bedoin et al., 2018)

Can the rhythmicity of a musical prime enhance the efficiency of therapeutic training and exercises, such as for syntax processing ?

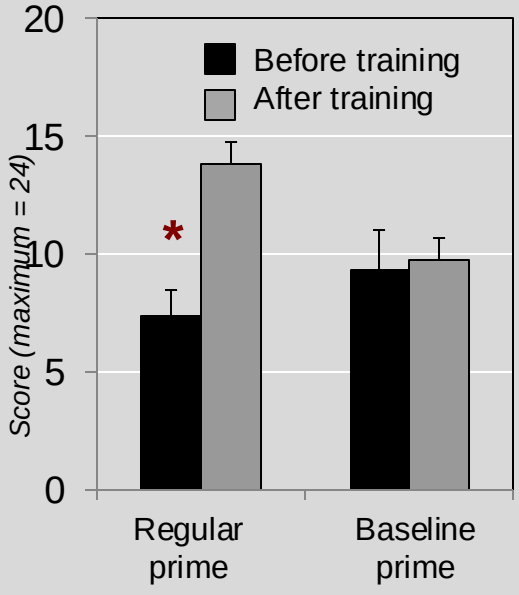
Hearing-impaired children with cochlear implants [N = 10 (mean age: 5;6 – 10;0)]

Syntax deficits in speech production and perception *(e.g., Tuller, 2000)*

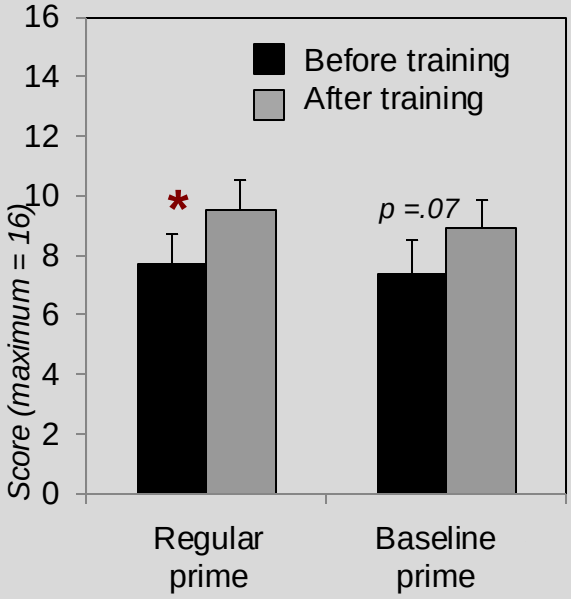
Hypothesis of more general impaired cognitive sequencing capacity *(Conway et al., 2009)*

Some reports for difficulties in rhythm processing *(e.g., Timm et al., 2014; Stabej et al., 2012)*

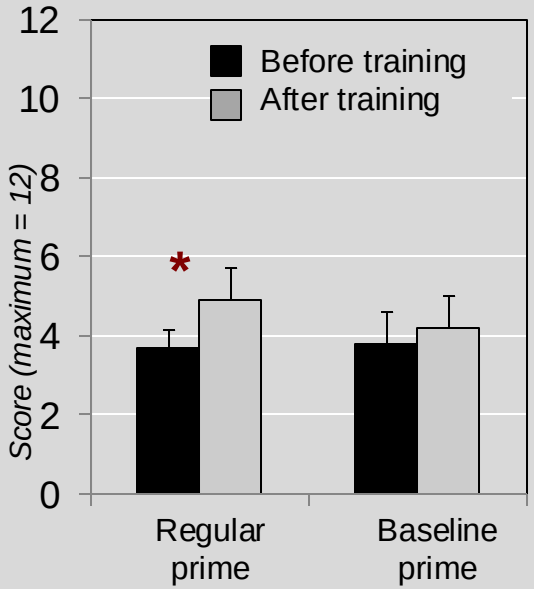
Grammaticality judgments



Syntax comprehension



Word/pseudo-word repetition

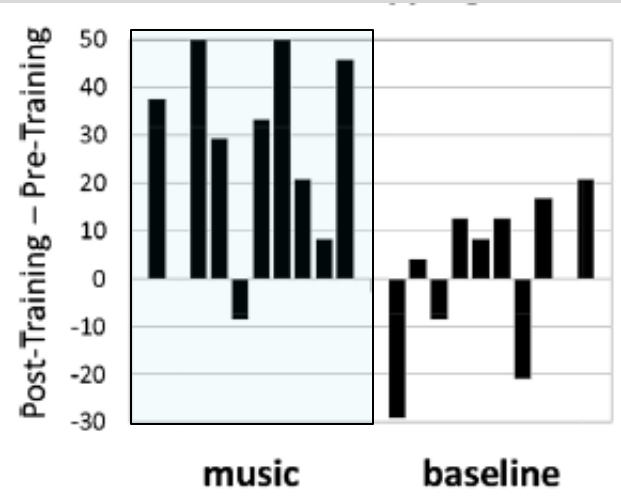


Improvement for some indicators in attention tasks; No improvement for memory tasks

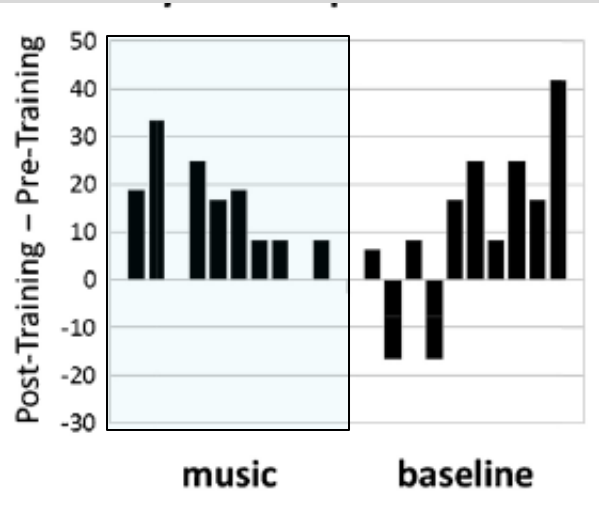
(Bedoin et al., 2018)

Can the rhythmicity of a musical prime enhance the efficiency of therapeutic training and exercises, such as for syntax processing ?

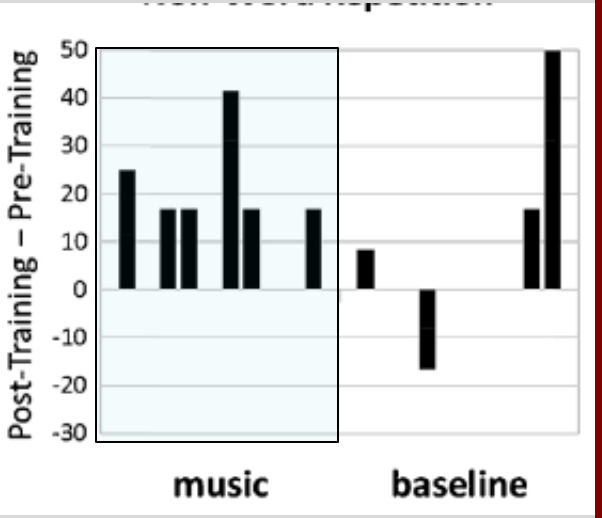
Grammaticality judgments



Syntax comprehension



Non-word repetition



Small sample size, but encouraging results:

The use of temporally regular musical primes might improve the benefits of morpho-syntactic training sessions in children with CI.

(Bedoin et al., 2018)

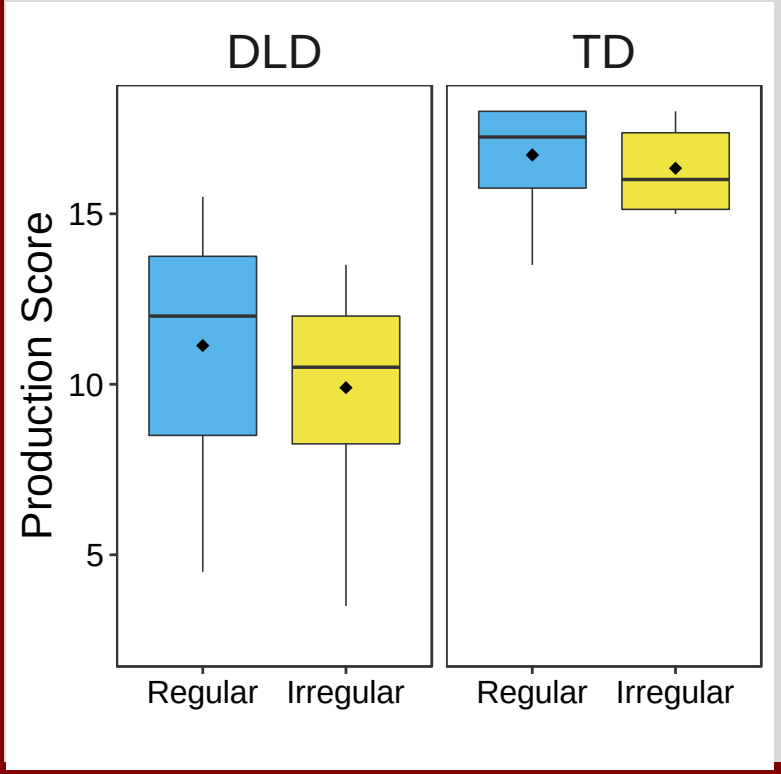
Benefit of auditory rhythmic stimulation on language processing

→ **Improved syntax processing** : grammaticality judgements
(& training intervention, Bedoin et al., 2018)

→ **Improved sentence repetition performance** *(Fiveash et al., 2023, npj science of learning)*

Rhythmic prime
Regular/Irregular

Repetition task (x6)



Subject-relative clauses:

This is the woman who saw Frank outside.
Elle est la femme qui a vu Frank dehors.

Object-relative clauses:

That's the cat that Tom hid from yesterday.
C'est le chat dont Tom s'est caché hier.

Filler sentences:

The children played in the park.
Les enfants jouaient dans le parc.

Children with DLD (n=15)
& age-matched TD controls (n=18)

Benefit of auditory rhythmic stimulation on language processing

→ **Improved syntax processing** : grammaticality judgements
(& training intervention, Bedoin et al., 2018)

→ **Improved sentence repetition performance** *(Fiveash et al., 2023, npj science of learning)*

→ **Improved syllable segmentation in reading** *(Bedoin et al., in prep.)*

Tasks that require sequencing and segmentation

BUT

Might it be only a general (arousal) effect beneficial to all tasks?

NO

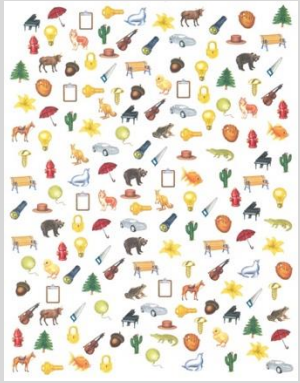
→ No benefit of regular primes for:

(1) Non-linguistic control tasks:

- Visuospatial search tasks *(Chern et al., 2018; Fiveash et al., 2023)*
- Math tasks (Chern et al., 2018)
- Non-verbal Stroop task *(Ladányi et al., 2021)*

(2) Linguistic tasks:

- Picture naming *(Ladányi et al., 2021)*
- Semantic evocation task *(Cannette et al., 2020; 2021)*



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→ **Improved syllable segmentation in reading** *(Bedoin et al., in prep.)*

Tasks that require sequencing and segmentation

→ Regular events of the musical prime provide predictable cues
→ Boosting and entraining internal oscillators
→ Benefit for temporal sequencing and segmentation

Dynamic Attending Theory

←→ **Temporal sampling (oscillatory) framework**
for dyslexia (and SLI) *(Goswami, 2011)*

Benefit of auditory rhythmic stimulation on language processing

←→ **Temporal sampling (oscillatory) framework** for dyslexia (and SLI) *(Goswami, 2011)*

←→ **Cortical oscillatory dynamics** in speech perception *(e.g., Arnal & Giraud, 2012; Morillon & Schroeder, 2015)*

… in rhythm and beat perception *(e.g., Fujioka et al.,2012)*

Isochronous tone sequence

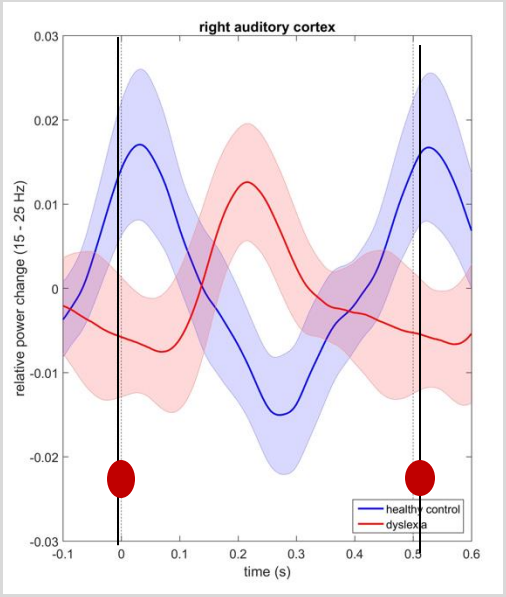
Beta oscillations:

* Beta decrease after stimulus onset

*** Beta rebound** = beta amplitude increased just before occurrence of next sound

(Fujioka et al., 2012)

Replicated in our controls



(Chang et al., 2021)

Not in dyslexic adults

Altered predictive timing?

→ Children with stuttering: Phase of beta power fluctuation opposite to controls *(Etchell et al., 2016)*

+ impaired auditory rhythm perception *(e.g., Falk et al., 2015)*

Processing Rhythm In Speech and Music: The PRISM framework

(Fiveash et al., 2022, Neuropsy)

OPERA hypothesis

Patel, 2011, 2014

Precise Auditory Timing Hypothesis

Tierney & Kraus, 2014

Temporal Sampling Framework

Goswami, 2011

Sound Envelope Processing & Synchronization and Entrainment to Pulse Hypothesis (SEP)

Fuji & Wan, 2014

Action Simulation for Auditory Prediction (ASAP)

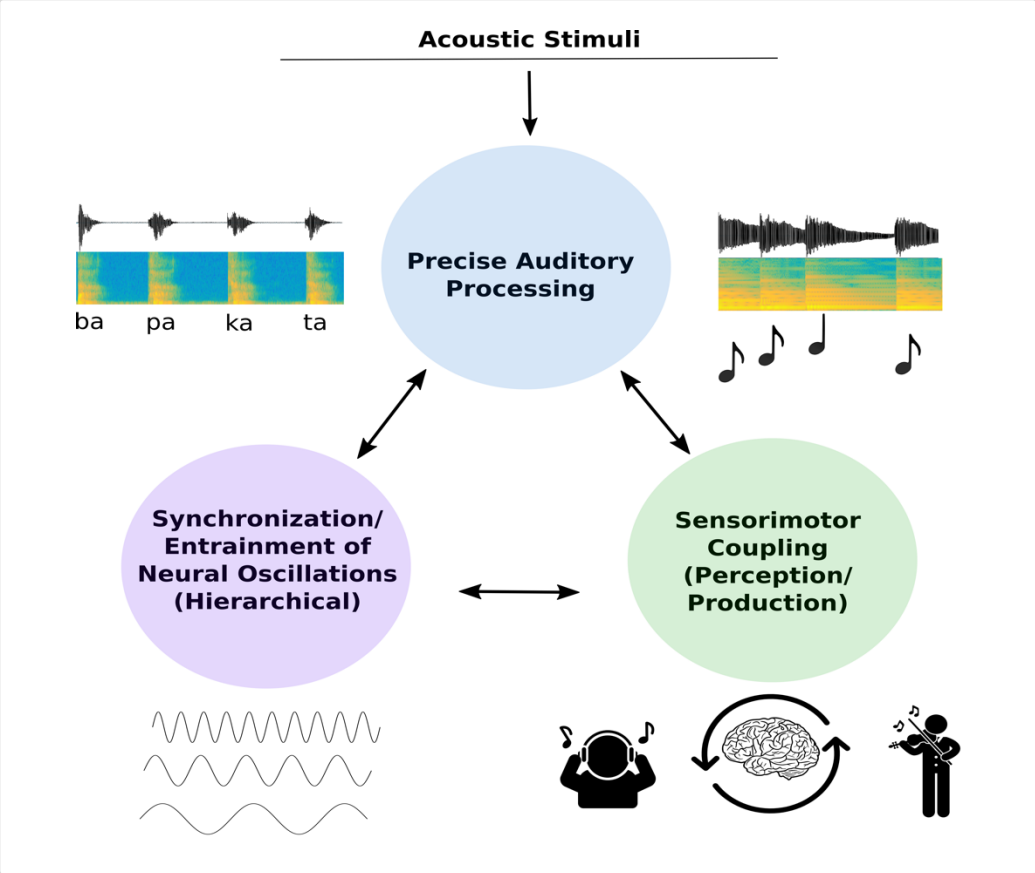
Patel & Iversen, 2014; Cannon & Patel, 2021

Active Sensing

Morillon et al., 2015; Schroeder et al., 2010

Processing Rhythm In Speech and Music: The PRISM framework

(Fiveash et al., 2022, Neuropsy)



Ability to discriminate very small deviations or changes in timing, pitch, and timbre.

Tracking of auditory rhythms, likely to underlie the perception of music and speech.

Connection between sensory and motor cortices.

Timing Deficits in Developmental Disorders

(Dyslexia, DLD, Stuttering, ASD, DCD, ADHD)

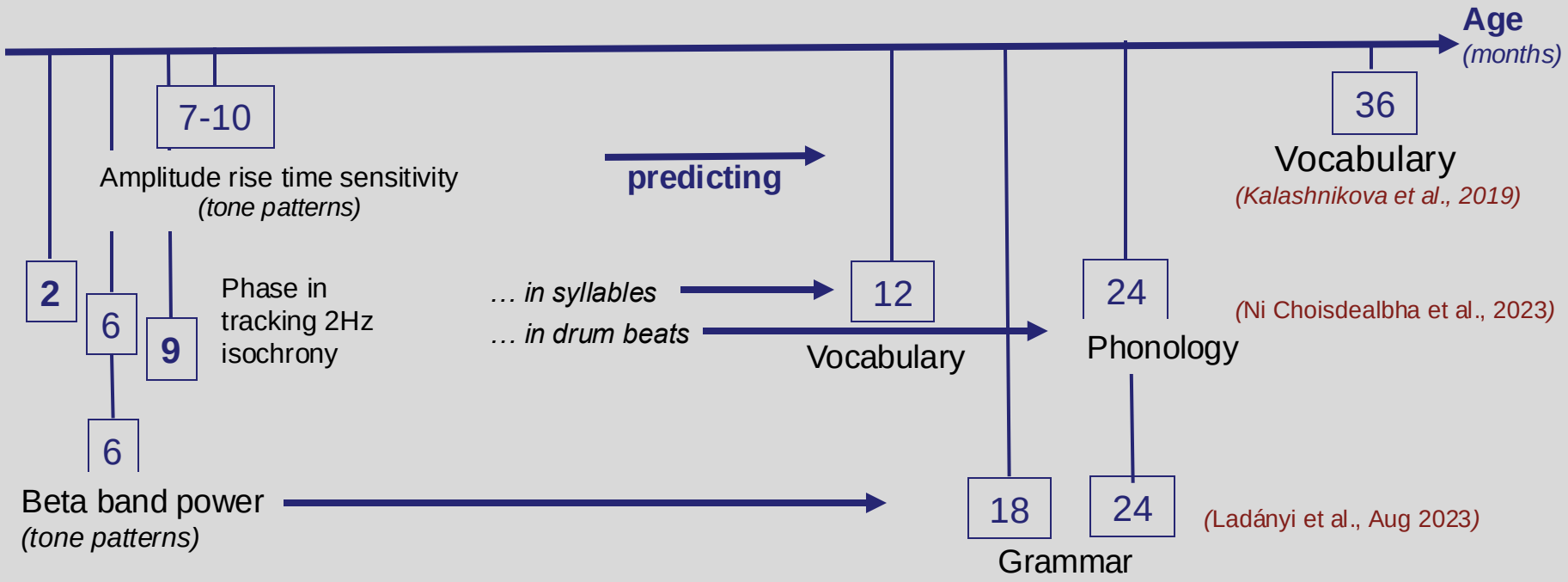
Atypical rhythm processing as a risk factor?

(Ladányi et al., 2020)

Music Rhythm Training to Complement Speech Therapy

Rhythm processing in music and speech

Early markers of (a)typical development?



Rhythm processing in music and speech

Competences | **Deficits** | **Training** | **Stimulation**

(Dyslexia, DLD, …) → **AGE**

Early markers of (a)typical development

Early rhythmic intervention

Premature infants

Prematurity:
- → Absence of rhythmic environmental sounds early in development
- → Hypothesis of disturbed auditory temporal processing capacities
- → Risk of impaired development of general cognitive capacities

Benefits of early music-rhythmic intervention in the NICU?

Music rhythm to complement speech therapy

Rhythmic priming in the elderly with pathology:

Parkinson Disease:
- Syntax perception *(Kotz & Gunter, 2015)*
- Speech production *(Contreras Roa, et al., 2022; Basirat et al., Univ Lille)*

Aphasia
- MIT → rhythm *(Stahl et al, 2014)*
- priming on speech production? *(with F. Rochette)*

Sahar Moghimi
Inserm, Amiens University

Laurel Trainor
McMaster University

THANKS TO

Anna Fiveash
Lyon Neuroscience Research Center & Western Sydney University

Nathalie Bedoin
Lyon Neuroscience Research Center

Laure-Hélène Canette
Lauranne Przybylski
Julie Camici
Karen Chidiac
Alexandra Corneyllie
Lyon Neuroscience Research Center

Philippe Lalitte
Emmanuel Bigand
University of Burgundy

Reyna Gordon
Eniko Ladanyi
Vanderbilt University

Sonja Kotz
Maastricht University

Vania Herbillon
Sonia Krifi-Papoz
Hospices Civils de Lyon

Laurel Trainor
Andrew Chang
McMaster University

Sahar Moghimi
INSERM, Amiens University

Annie Dumont
Eliette Escandre
Anne-Marie Besombes
Rothschild Hospital, Paris

Didier Roch
Lucy Brisseau
Pauline Molinier
IME, Paris

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ERASMUS MUNDUS

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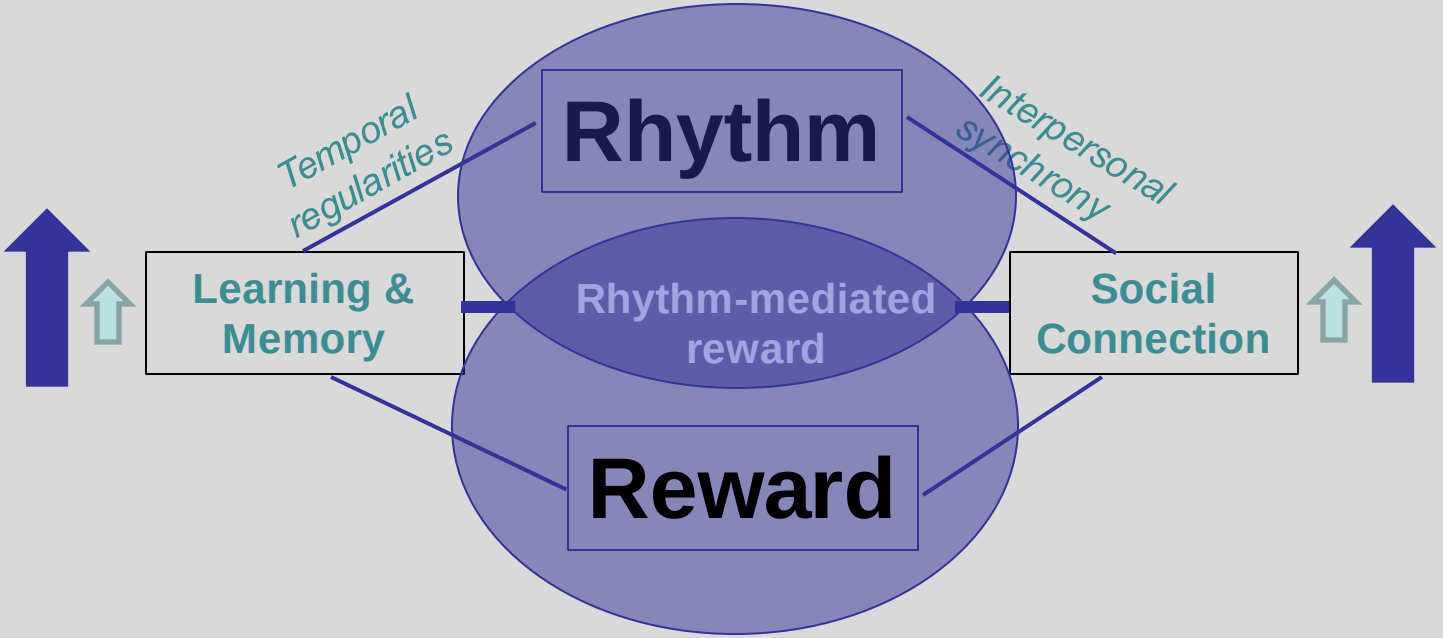
REGION BOURGOGNE FRANCHE COMTE

THANKS FOR YOUR ATTENTION

Open post-doc position
(Dijon, France)



(Fiveash, Ferreri et al.,2023, Neuroscience and Biobehavioral Reviews)